LOW DENSITY COMPLETION SLURRIES DEVELOPED FOR PARTIALLY DEPLETED RESERVOIRS

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ABSTRACT

Cementing production casing in partially depleted reservoirs is a common problem in the Permian Basin. The industry is continually looking for alternative slurry designs to lower annular pressures during cementing while maintaining the material properties needed for stimulation and zonal isolation. In order to be viable, the resulting technology must decrease density while preserving compressive strength, fluid loss and free water properties of the cement. Cement slurries using foam or hollow spheres are capable of meeting these requirements. The additional equipment and material cost required usually prevent these systems from being economical when mixed between 13.5 and 14 ppg (lb/gal).

Recent technical developments have lead to the creation of slurries weighing 13.8 ppg containing 60% pozzolan and 40% API cement. These economical slurries exhibit mechanical properties comparable to standard API slurries having much higher densities. Laboratory testing and bond logs are presented and compared along with recommended applications.

INTRODUCTION

Formation pressures throughout West Texas and Southwestern New Mexico have steadily declined since production from these fields began. Low formation pressures have created significant challenges for drilling and completion. Many of these fields have been placed on water flooding programs in an effort to maintain formation pressure. Stage tools and/or low-density slurries are often used to avoid loosing circulation while cementing.

Three techniques are commonly utilized for low density cementing:

1. Foam slurries have been used since the early 70's. Initial research was conducted at the Colorado School of Mines as well as several Russian research institutions'. While conceptually attractive, the challenges of producing uniform foam cement throughout the desired annular space have been significant*. Recent developments in computer control systems have significantly improved the capability to produce uniform foamed cement. This technology and the associated equipment required significantly increases the cost of cementing.

2. The use of lightweight glass or ceramic beads to lower density was introduced in the same time frame as foam cementing.' Due to the high cost of these materials, this technology is cost prohibitive for typical slurry volumes in all but the most prolific wells.

3. Fly ash or pozzolan may be used to decrease slurry density due its lower specific gravity compared to cement. Historically, this option has been limited by the degradation of slurry properties when high ratios of pozzolan are used. Recent additive developments have enabled slurries with pozzolan ratios greater than 50% and densities below 14 ppg to achieve mechanical properties comparable to completion slurries with much higher densities.

DEVELOPMENT

Type F fly ash is a low-cost and readily available byproduct of coal combustion. Commonly known in oilfield operations as pozzolan or 'poz' it is often used as a cement extender. The beneficial properties of pozzolan, a highly reactive silica, combined with cement have been recognized by the construction industry for many years. As lime is liberated during the hydration of cement it reacts with pozzolan to form calcium silicates and aluminates. These by-products increase the density and decrease the permeability of the set cement slurry contributing to compressive strength development. This reaction also reduces the amount of lime present to react with organic acid, thus producing a more acid resistant cement[3,4]. The partial replacement of cement with pozzolan reduces the over-all heat of hydration, thereby reducing the propensity to develop thermal cracks at lower temperatures[5]. Pozzolan has a specific gravity of 2.5 as compared to 3.16 for Portland cement. This density difference results in decreased slurry density in pozzolan blends.

Portland cement blends with densities between 14.5 and 15 ppg containing 50% pozzolan, 50% cement are common completion slurries. Blends containing 35% pozzolan and 65% cement plus bentonite mixed to a density between 12 and

13 ppg are often used as filler or lead cements. Proprietary additives have been used with these cements to increase compressive strengths to 2500 psi or greater allowing these specialty low-density slurries to be used as completion slurries.

Historically, increasing the pozzolan ratio above 50% has resulted in a significant reduction in properties, including compressive strength. A recent development in the processing of pozzolan has resulted in the development of a highly reactive processed pozzolan. This product combined with standard oilfield pozzolan has lead to the development of slurries containing 60% pozzolan and 40% Portland cement. These high pozzolan slurries can be blended at densities of 13.8 but exhibit the compressive strength development, fluid loss and free water properties of industry standard high-density completion slurries. The relatively low density of this system makes it an attractive alternative to foam or lightweight sphere systems in moderately pressure depleted reservoirs.

CASE HISTORIES

Well #1 Eddy County New Mexico

This well is located in the Ingle Wells Field in Eddy County New Mexico. Intermediate casing was set at 4400 ft. The well was then drilled to a TD of 8500 ft with a bit diameter of $7^{7}/_{8}$ inch. Prior to cementing, the well was conditioned by circulating while reciprocating for several hours. The 9.0 ppg drilling mud was then displaced with a spacer system placed in turbulent flow. This spacer consisted of 2000 gal water followed by 1500 gal of water containing 190 lbs/1000gal sodium acid pyrophosphate (SAPP). **A** lead slurry consisting of 279 ft^3 of a 12.5 ppg blend containing 35% Poz, 65% Class C and 6% BWOC bentonite was followed by 1225 ft^3 of 13.8 ppg high pozzolan slurry. The designed top of cement (TOC) was 4000ft with 400 ft inside of the 8 *5/8* inch intermediate casing. The planned TOC of the high pozzolan tail slurry was 4600 feet.

Laboratory tests conducted with this high pozzolan slurry are given below:

Free water - 0.0 mls @ 127 °F, 90° angle
Fluid loss - 100 cc/ 30 min @ 127 °F, 1000psi
Compressive Strength @ 142°F:

12 hour	1100 psi
24 hour	2150 psi
48 hour	2700 psi
72 hour	3000 psi

The Lead and Tail slurries both contained ¼ lb/sack cellophane flake and a bridging lost circulation material. A VDL bond log was run 8 days after cementing. An examination of the log indicates that the lead TOC was at approximately 4100 feet. There is a notable improvement in the VDL log at 4449 feet, as shown in figure 1, indicating that this is most probably the top of the high pozzolan tail slurry. Figure 2 is representative of the bond obtained from the remainder of the tail slurry.

Well #2 Hansford County Texas

This 7155 foot well was drilled with 9 lb mud using a $7^{7}/_{8}$ inch bit. A 4% inch longstring was run to TD. A low pressure zone dictated that the maximum equivalent circulating density be kept below 11 ppg. The design requirements called for cement coverage from total depth to 4100 feet. **A** slurry with compressive strength in excess of 2000 psi was desired in order to provide the zonal isolation required for stimulation.

Due to the low formation pressure gradient, wells in this area are typically completed with a stage tool at 6000 feet. Thixotropic Class H slurry blended at 14.8 ppg is utilized to cement the first stage. A 15/85 Pozzolan/H slurry mixed at 12.5 ppg followed by 50 sacks of 15.6 ppg Class H is used for the second stage. Nitrifying the mud ahead of cement with 350 scf/bbl is still needed on both stages to keep the ECD below the maximum of 11.0 ppg. Figures 3 and 4 show the maximum calculated ECD as a function of depth for stages 1 and 2 respectively as calculated by a cementing simulator[6].

Based on computer simulations it was determined that wells in this area could be completed in a single stage by a combination of nitrified mud and high-pozzolan low-density cement. Laboratory tests indicated that a blend of 60140 Poz/C with 4% reactive processed pozzolan and a bonding additive containing a high molecular weight polymer would achieve compressive strengths over 3000 psi at 165°F.

The following table summarizes the measured values:

Free water - 0.0 mls @ 124°F, 90° angle
Fluid loss - 150 cc/ 30 min @ 124°F, 1000psi

Compressive Strength @ 163°F:

12 hour	1400 psi
24 hour	2350 psi
72 hour	3100 psi

During the job, nitrogen was utilized to lower the mud weight ahead of the cement by adding 675 scf/bbl for 32 barrels of mud. This was followed by 37 bbl scavenger cement composed of a high pozzolan blend with a density of 11 ppg. Density was then increased to 13.8 ppg for the 580 sack, 139 bbl, primary slurry. Figure ***5*** shows the maximum ECD calculated for the cement job.

A CBL/Gamma log was run 18 days after cementing. The well was logged from TD to 4000 feet with 1000 psi surface pressure to minimize the effect of any micro-annulus. A section of the log is reproduced as figure 6.

Well #3 Anton-Irish WolfCamp

The Anton -Irish (Wolfcamp) field in Lamb County Texas is typical of a pressure-depleted reservoir. This oil reservoir has an average gross thickness of 500 ft with an average total depth of 6100 ft. The formation was originally a solution gas driven reservoir. Water flooding was begun in 1969[7] and is now the principal drive mechanism. The original reservoir pressure gradient is 0.33 psi/ft or 6.35 ppg equivalent. A 0.6 psi/ft fracture gradient is common.

Well #3 was drilled with an 8.75" bit to 6653 ft. Seven inch casing was run to TD with a stage tool at 5280. A 14.2 ppg Class C cement, Pozzolan, fume silica blend with an expansion additive was used for the first stage. The second stage was cemented with a 2700 ft^3 of a 12.5 ppg lead slurry containing 35% Poz, 65% Class C and 6% BWOC bentonite. The tail cement was 275 ft^3 of 13.8 ppg high pozzolan slurry.

The static temperature at 5200 feet is approximately 113°F. The laboratory measured compressive strengths for the high pozzolan slurry are as follows:

Compressive Strength @ 113°F:

12 hour	950 psi
24 hour	1850 psi
72 hour	2500 psi

A segmented bond log was run 80 days after cementing. A section of the log beginning at the stage tool is re-produced as figure 7.

The well was later deepened to 7072 feet with a 6.125" bit. **A** 4.5 inch liner was cemented from TD to the liner hanger set at 6017 feet with 125 sacks of high pozzolan slurry mixed at 13.8 ppg.

CONCLUSIONS

The addition of highly reactive processed pozzolan to standard pozzolan has enabled completion slurries to be developed with densities below 14 ppg. These slurries containing 60% pozzolan and only 40% API cement exhibit the mechanical properties of higher density slurries. The advantages to be gained by the addition of pozzolan are retained without the strength reduction usually seen when slurries contain more than 50% pozzolan. Bond logs demonstrate that these slurry systems can be utilized to provide the zonal isolation with the strength required of a completion slurry. This provides an intermediate step between industry standard completion cements and more expensive foam or hollow sphere based systems.

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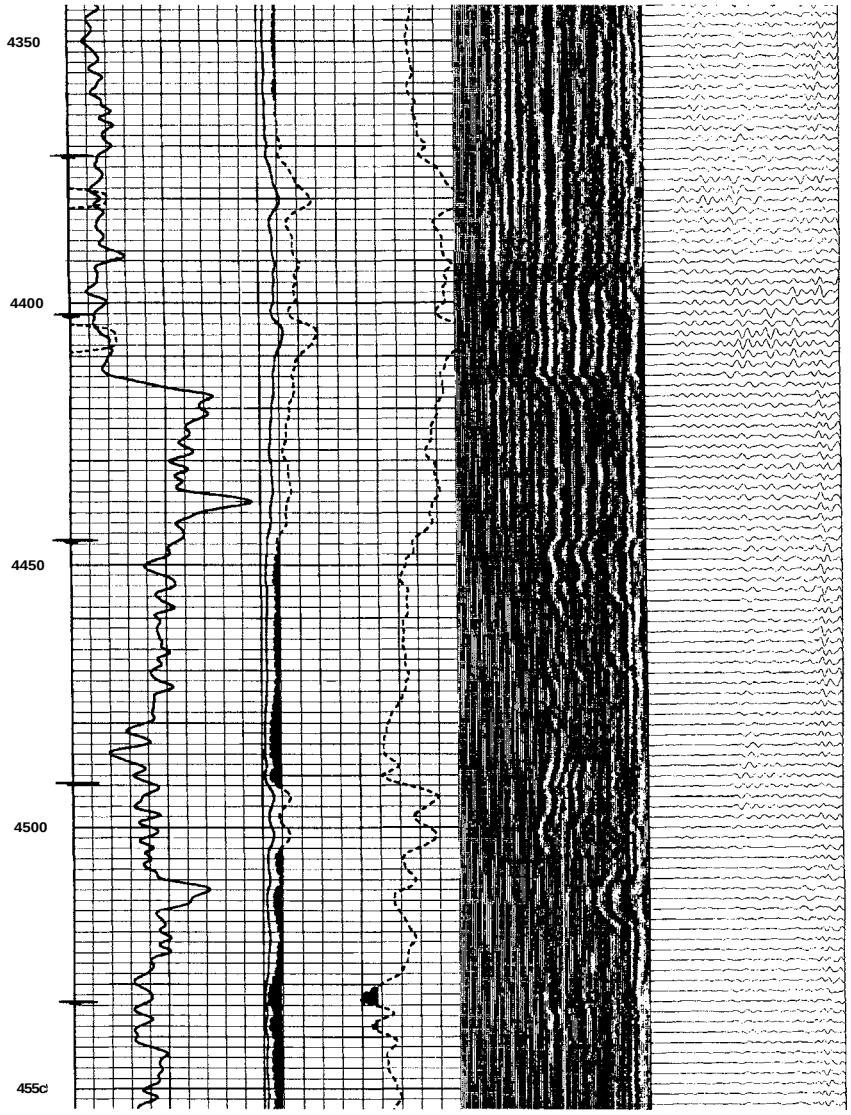

Figure 1 - Well 1 Bond Log at Top of Tail 4350-4550

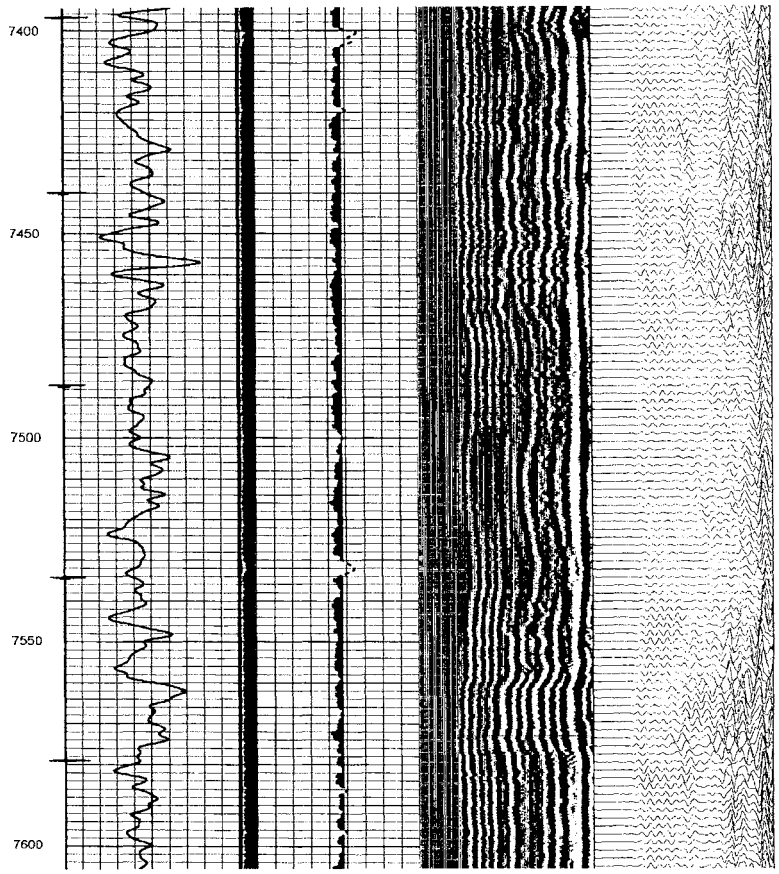

Figure 2 - Well 1 Bond Log High Pozzolan Slurry 7400-7600

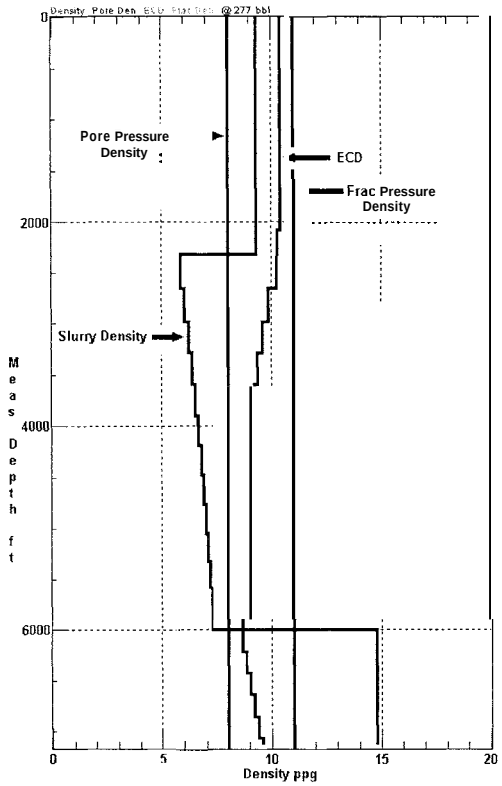

Figure *3* - Maximum ECD Well 2 Stage 1

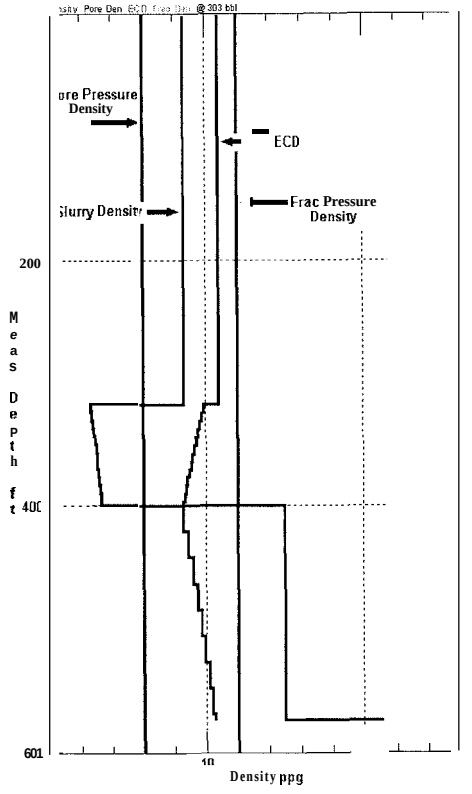

Figure 4 - Maximum ECD Well 2 Stage 2

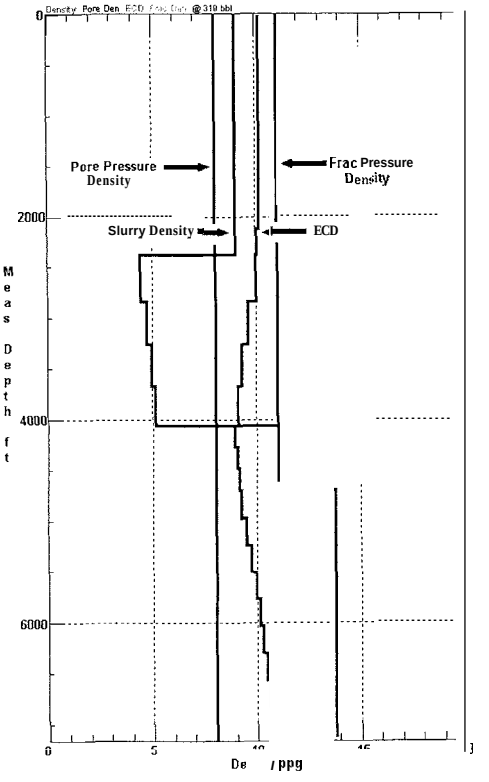

Figure 5 - Maximum ECD Well 2 Single Stage

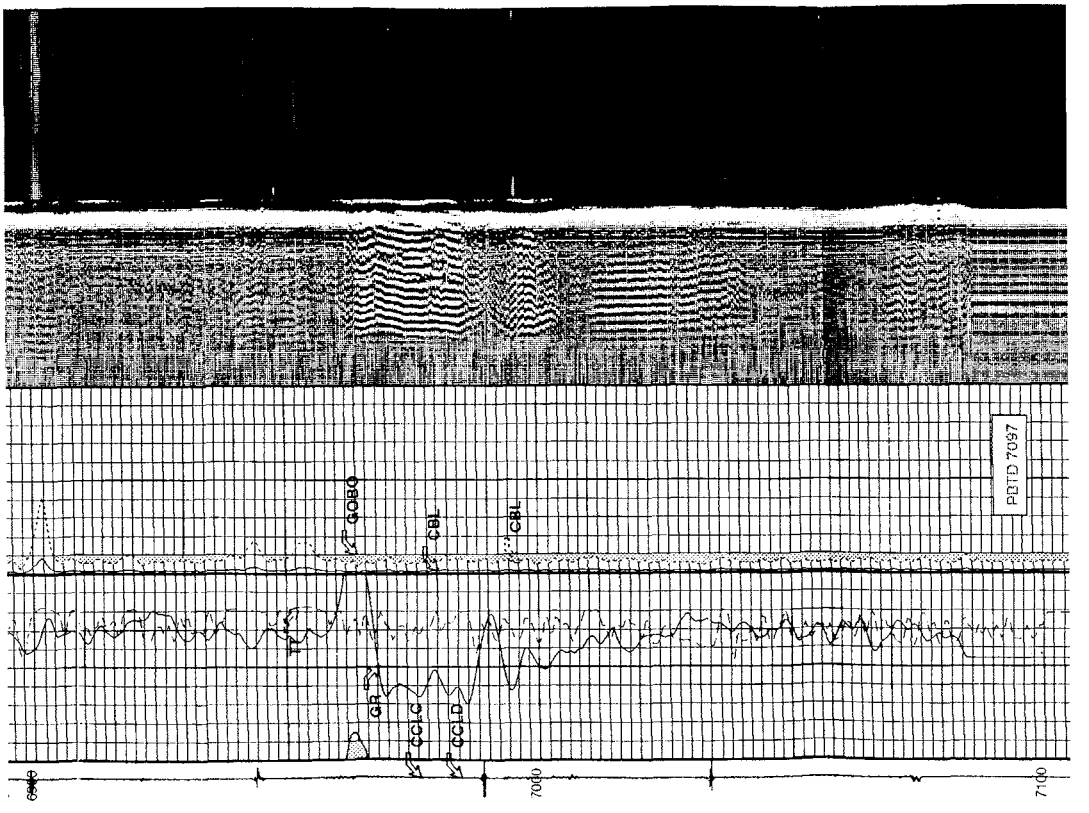

Figure 6 - Well 2 Bond Log High Pozzolan Slurry

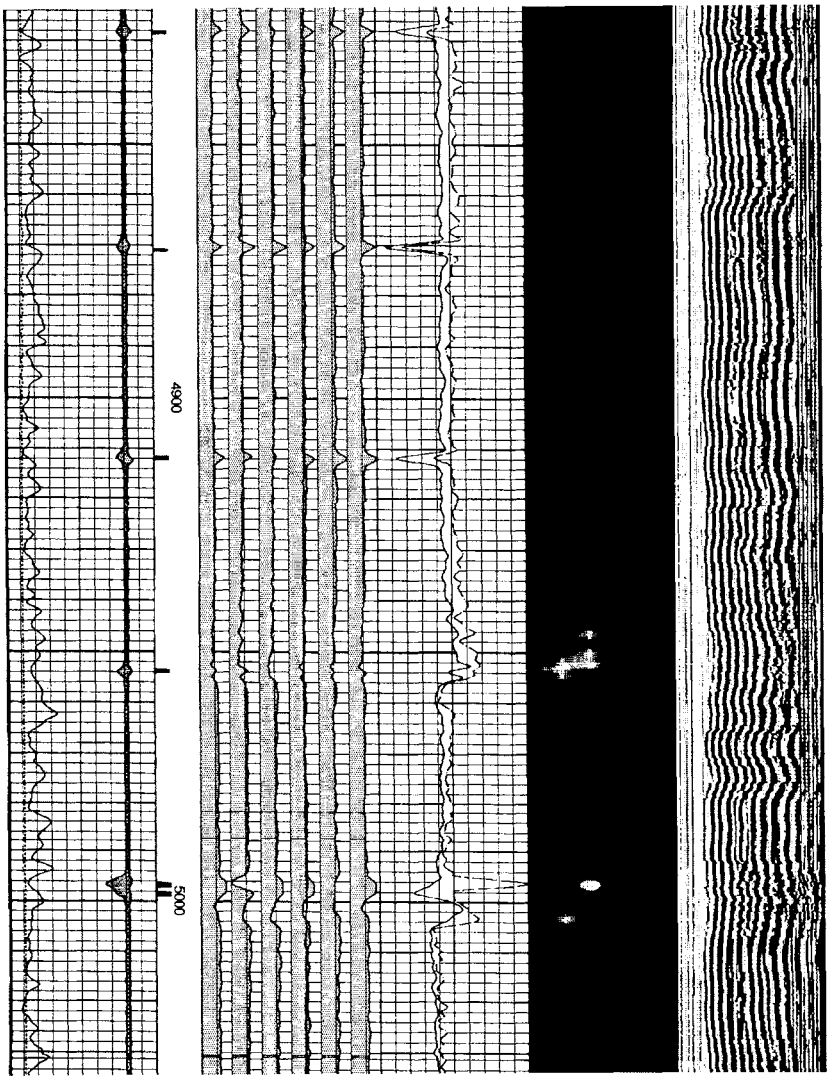

Figure 7 - Bond Log Well 3 High Pozzolan Slurry